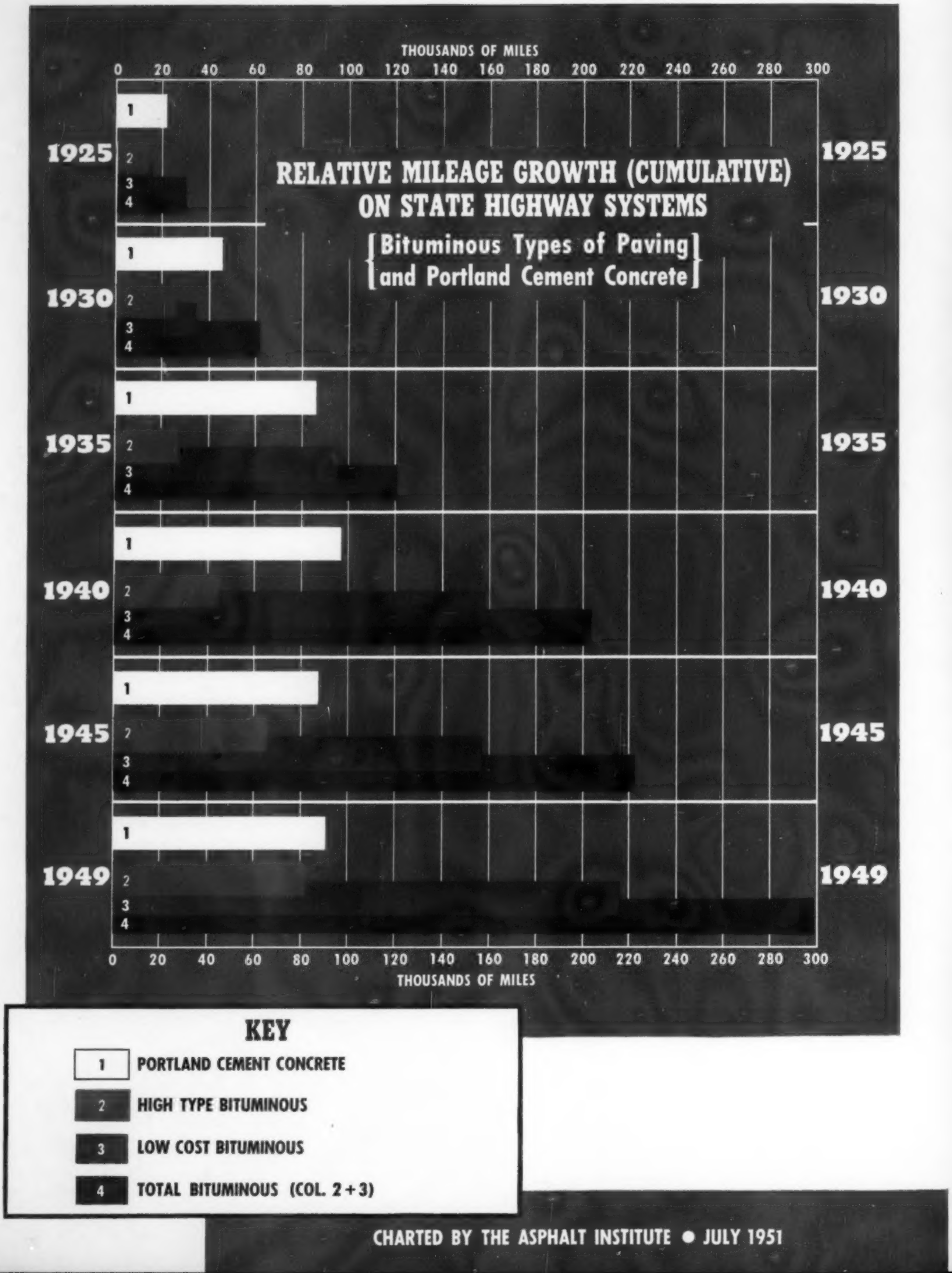
ASPHALT INSTITUTE *Quarterly*

JULY 1951


RELATIVE MILEAGE GROWTH (CUMULATIVE)
ON STATE HIGHWAY SYSTEMS
Bituminous Types of Paving
and Portland Cement Concrete
THOUSANDS OF MILES
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
1925
1930
1935
1940
1945
1949
1
2
3
4
KEY
1 PORTLAND CEMENT CONCRETE
2 HIGH TYPE BITUMINOUS
3 LOW COST BITUMINOUS
4 TOTAL BITUMINOUS (COL. 2+3)
CHARTED BY THE ASPHALT INSTITUTE ● JULY 1951

ASPHALT INSTITUTE *Quarterly*

VOL. 3 No. 3 JULY 1951

The Asphalt Institute Quarterly is published by the Asphalt Institute, a national, non-profit organization sponsored by members of the industry for the purpose of promoting interest in the use of asphaltic products.

The names of the Member Companies of the Institute, who have made possible the publication of this magazine, are listed herein on page 15.

EDITORS

Bernard E. Gray, *President of The Asphalt Institute*
Ernest M. Bristol, *Director of Public Relations*

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Highway Re-appraisal Issue

Articles may be freely reprinted with credit line. Correspondence should be addressed to the Asphalt Institute Quarterly, 801 Second Avenue, New York 17, N. Y.

COVER

Featured on the double covers is a picture taken by "Howard Staples & Associates" and Rodney Ryker, District Engineer, The Asphalt Institute, showing the asphalt penetration macadam highway on U.S. Route 410 (State Road No. 5) in the State of Washington. This scenic area is near the summit of Chinook Pass, has an elevation of 5,000 feet, and is subject to heavy snows up to 15 feet.

Chart Statistics — The most recent mileage figures charted on the opposite page are taken from the tabulation of the U.S. Bureau of Public Roads for 1949, the latest year reported. Earlier totals are based upon the Highways Education Board figures for 1925 and those of the American Association of State Highway Officials for the intervening years.

EDITORIAL

Some thirty-odd years ago, in a mid-southern state, a meeting was underway where plans were being discussed relative to establishment, for the first time, of a state highway department. In the hallways adjacent to the meeting room there were the usual small groups in conversation, and from one came this remark, "I'm a brick man, myself." Thus often did county officials express their views on pavement design. It was natural enough for him, because they made brick in his county, and there were plenty of skillful layers of brick available. In some other parts of the country the county official might have been an asphalt man, or a wood-block man, or a concrete man for, in those World-War-I years, very few people had yet thought in terms of a widespread coordinated system of roads. Rather, in each county or township, the principal concern was to have a "hard" road from the country to the Court House; one that once built would last a long time without much upkeep, particularly if financed by a bond issue.

Looking back at the record, one will find that the proceeds of many such local bond issues were expended on pavements which often cost nearly as much per unit as the most expensive ones laid today. Because they were so costly, there was a tendency to cut down on the alignment and structure costs, with resulting curves and heavy grades out of proportion to over-all improvement. For some years these deficiencies were not too apparent, for vehicle speeds were low and traffic volume was small; but by the mid-twenties this condition began to change. With increased traffic, such faulty locations became more and more apparent yet, because the investment in pavement was so high, they remained "frozen" in place despite lowered costs for grade relocation. There were exceptions, particularly in states that had only small bond issue improvements, and where the state engineers had followed fundamentally sound transport development principles; namely, to get some kind of an improvement through from terminus to terminus at the lowest possible cost and then provide betterments out of earnings. Initially low-cost surfaces fitted well in such sound planning.

In our highway transport system earnings are derived in large degree from a use-tax on motor fuel, and the increase in traffic volume has been sufficient to provide the funds needed to further improve the system, wherever a proper stage-construction development program has been followed. In the present post-war period, however, now some six years along, there is an accelerated increase in traffic, not only in volume but now particularly in weight. While the state systems vary considerably in their current inadequacy, depending on past practices, the traffic is there and must be carried.

Thus, if these systems are to be brought up to the standards required for efficient motor vehicle operation within the reasonably near future, it will be done only as the result of a complete *re-appraisal* of present procedures involved in design, construction, and maintenance,—plus a more efficient expenditure of the funds currently available. As a practical matter it is becoming less and less feasible to increase the rate of taxation, because a tax-burdened people simply cannot and will not carry the extra load. No longer can the matter be settled by the statement, "I'm a brick man, myself." Every possible local resource must be evaluated. This includes making fullest practical use of every improvement already made and the adoption of design procedures which will provide additional ones at lowest costs.

The Newburyport Turnpike in Massachusetts, 5½" Hot-Mix asphalt over 14" gravel, traffic count 15,000 to 20,000 vehicles per day; annual maintenance costs less than one-half cent per square yard. *Photo Howard*

HIGHWAY PAVEMENT DESIGN

by BERNARD E. GRAY

President of the Asphalt Institute

This article is based upon Mr. Gray's forty-two years experience in building highways. During the first half of that period, associated with the State Highway Departments of Massachusetts and West Virginia, as well as the U. S. Bureau of Public Roads, he filled practically every position involving surveys, design, construction, and maintenance. Since 1930 he has been with the Institute and during this period, in addition to studies in the forty-eight states and Canada, has observed work in Latin America, Great Britain, and Continental Europe.

A typical residential street in Scarsdale, New York, paved with asphalt penetration macadam; maintained indefinitely with occasional light seal coat. *Photo Gray*

INTRODUCTION

This article on the design of highway pavements is not intended to be a technical discussion. Instead, it is hoped to present a broad picture of the history of highway development and some of the reasons why the trend of the times now makes it necessary, as well as desirable, to follow certain procedures. For the thousands of readers of the Quarterly who are not engineers yet who, as legislators, administrators, and editors, are in positions of great responsibility to see that economical and efficient expenditure of public funds is obtained, these pages possibly may be helpful in arriving at appropriate conclusions with respect to future highway development needs.

Highways cost money — a great deal of money. Where one hundred cents benefit is secured for each dollar expended, they are worth everything they cost. Where expenditures, however, are made just for a special project here and there to the exclusion of needed improvements elsewhere, or where any kind of work costs more than it should, the road user has every right to question the wisdom of the procedures employed. The statement has been made that highways are already quite worn out, and will collapse completely in a relatively few years' time, unless huge additional sums are made immediately available for their replacement. Is this a fact or is it, in some part at least, an exaggeration? The taxpayer has a right to the correct answer and to date most reports on the subject leave much to be desired. No one of experience questions the need for continuous repair and periodic rehabilitation, as this is but good management for any kind of facility. What is questioned however, is the lack of judgment at times displayed in not doing first things first.

Sometimes the picture is confused further by arguments that increased taxation for roads is justified on the ground that it will cost each automobile owner only a few cents a week more and that he should not complain as other articles he uses have increased a lot more percentage-wise. This is not sound reasoning, and not likely to convince the already overloaded taxpayer that he should take on additional burdens. People will pay tolls on a bridge or a particular road because they see exactly what they are getting. Rightly or wrongly, so far as the principle of toll roads is concerned, this is a fact. Highway departments must present the merits of free roads in the same clear fashion if they expect to have the desired response. Once this is done, appropriate financing will follow as a matter of course.

It is to be hoped that the plan for a National Inventory, as outlined in February of this year by the Association of American State Highway Officials, may give a better answer to the question.

It may be blunt to say so, but much of the current resistance to further taxation for highways is based on the suspicion that the user is not always obtaining a full return on his money, and that if the funds presently available were employed more efficiently, more and better highways would result. While a number of our highway departments are run very well indeed, there are others so handicapped by inadequate legislation, low salaries for technical personnel, and restrictions of one kind and another, that it is perhaps remarkable that they function as well as they do. It is needless to say, however, that if highway development is to proceed in the needed manner, correction of these deficiencies should be a first consideration.

Highways to be properly designed, built, and maintained, require skilled personnel. The older engineers, who largely built the system now in use, are fast being retired. Replacements with men of similar ability and training are increasingly difficult to obtain under present conditions, as may be verified readily by noting how few recent graduates of our technical schools are being attracted to public work. This is a most serious matter, and the condition will become worse before it changes for the better. So, as an introduction on the subject, attention is directed to this pressing need for placement of every highway department on a strictly business basis, with salary scales and working conditions adequate to attract and hold the qualified personnel that will be required to operate the better integrated highway system of the future.

HISTORY OF HIGHWAYS

Before going into details concerning pavement design, it may be appropriate to define what is meant by a highway, and a highway pavement. Like so many of our everyday facilities, we are apt to take improved highways and pavements pretty much for granted; but actually the present scale of development is of very recent origin. Someone has defined a highway as a line of communication made by man for vehicular and pedestrian traffic from one place to another. The radius of travel for a pedestrian is usually not very great, and even horse-drawn vehicles were limited to movements of tens of miles per day. The early highways were thus distinctly a local responsibility until well into the twentieth century. Reference is made to the "town road" or the "country road," while the term "state roads" did not become common in the United States until well after 1910, when the "horseless" vehicle had demonstrated its potentialities.

Emphasis is desirable on this effect of the *vehicle,* because it is always the determining factor in the kind of pathway that ultimately will be constructed from one place to another. At the present time this vehicle is automotive and there are nearly fifty million of them in the United States. Because the internal combustion engine is efficient, because metals for construction of frames and bodies are strong, and because rubber tires have become extremely durable, it is now possible to move people and goods rapidly and cheaply from one place to another over a highway. Thus in contrast with the earlier purely local roads, with slow moving vehicles, we now have need, not only for state roads, but for complete integration of the several state systems into a national roadnet, so that these faster moving vehicles may be used in the full range of their capacities.

It is inevitable that transport of goods as well as people over the highway will increase both for the long haul and the short haul. Certain routes, in addition to passenger car traffic, now are attracting long haul, heavy truck and bus movement. There is the transport of fuel and food by vehicles, and the inter-industry movement of raw materials and partially processed manufactures in cities. These highway uses have developed rapidly, and they must continue to expand. It is clearly evident, therefore, that to provide properly for various future needs, greater care must be taken in forecasting the type of traffic that is to be expected on a particular highway. To this end far greater cooperation between highway departments and industry must be had, in order that the problem be mutually understood. Traffic of course should pay for the improvements required, but it is necessary also that the road-user be fully informed as to costs and whether there are alternate methods for making the improvements, some of which may be more economical than others.

The dimensions of a highway are *length, width,* and *thickness.* The item of length, which includes all the convolutions such as intersections, will not be covered herein. Engineers have termed this aspect of highway layout, *geometrics,* which often is quite apt when one looks at some of the complicated traffic interchanges in and adjacent to cities. This discussion, however, will be entirely on the basis of everyday arithmetic, and will cover the other two items of *width* and *thickness* as required on present day highways to serve present day traffic.

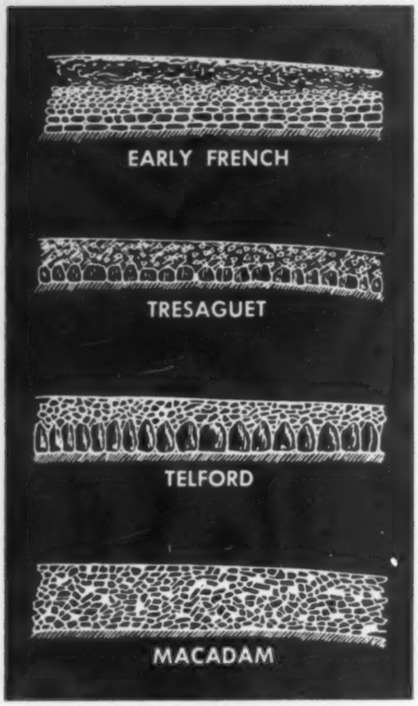
BROKEN STONE PAVEMENTS

While lines of communication are as old as history, the paved highway as we know it today is of comparatively modern development with possibly one or two exceptions, such as the Incan paths in South America and the roads of ancient Rome. The latter probably represent the earliest organized construction on any substantial scale and some of the famous highways such as the Appian Way, built about 300 B.C., are still in use as foundations under modern type resurfacing. Having plenty of slave labor,

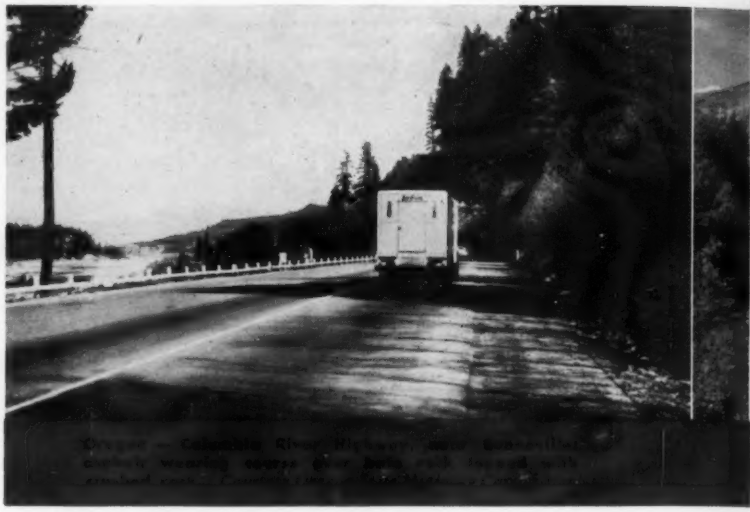
Continued on the following page

Modern Appian Way north out of Naples; bituminous-paved, and used for all types of travel. *Photo Galloway*

Ancient Appian Way, showing construction methods employed by the early Romans.
Adaptation of the U.S. Bureau of Public Roads Model.



EARLY BROKEN STONE PAVEMENT CROSS-SECTIONS



the cost of these early roads was not too important an item, and consequently the placement of four layers of material largely stone, to depths of three feet or more, presented no particular problem. These roads, primarily military in character, provided for quick movement of troops and supplies in the process of maintaining government functions throughout the Roman Empire. After the disintegration of this far-flung Empire, organized road building lapsed for many centuries. Even in France, one of the most civilized countries of the Middle Ages, roads seem to have been largely of earth, and not too well maintained during bad weather.

It was not until about the middle of the eighteenth century that we find a revival of the art of organized paving, and possibly three men merit a large part of the credit for the improved conditions. One was the Frenchman, Trésaguet. In contrast with the Roman method of placing the large base rock in horizontal position, Trésaguet had them made of shorter dimension and placed vertically. He also reduced the thickness of the upper layers, and this improved method was employed even in recent times. The English engineer, Telford, was notable, not only for the particular kind of stone base which bore his name, but because of his insistence upon proper drainage of pavement after construction. He used large stones, selected rather carefully, and placed on edge, thus making a very solid type of stone block foundation. Many roads of this type were built later in the United States, particularly on the several turnpikes that were constructed in the early nineteenth century. Some of these Telford type roads were uncovered by the writer in building roads in West Virginia, and portions of them still serve (1951) as foundations for the new pavements laid over them.

McADAM'S FUNDAMENTALS

The greatest name of all, however, is that of John Loudon McAdam, because he set forth the fundamental principle which governs all good roadbuilding. This all-important item was and is that the sub-soil, no matter how poor in quality, will carry any weight if it is kept dry by proper drainage and waterproofing of the surface. McAdam eliminated the large unwieldly base rock, and placed the broken stone directly on the natural soil, which however was first well drained. He expressed the opinion that a 10-inch thickness of stone so placed would support the heaviest traffic, and this opinion was subsequently borne out by actual experience during all the rest of the horse-drawn era. Where Telford placed a cover of fine gravel over the broken stone as the final surface, McAdam insisted that stone dust alone be the binder, and where good cubical shaped particles of rock were available this method did indeed prove to be superior, so long as traffic consisted of slow moving iron tired vehicles. McAdam was a good organizer and a capable writer, and even with changed traffic conditions, which now make untreated macadam surfaces suitable principally for base courses, the improvement which he brought about in construction and maintenance was the real beginning of an organized highway system as we know it today.

SOME EARLY PAVEMENT TYPES

In the light of this early history perhaps it may be asked, what constitutes a pavement? In simplest terms, a pavement is *any kind of a composite base and surface which is adequate to carry the expected traffic.* It is important to keep this definition in mind, because it places in true perspective the great variety of surfaces in relation to their ability to take care of traffic. In other words, a simple surface treatment which adequately supports traffic at reasonable cost, is just as much a pavement as the heavy structures that may be required to carry the heaviest traffic. In this connection it is becoming more and more apparent that, regardless of type of traffic, the wearing surface can be relatively thin, provided the natural ground and selected foundation courses are properly placed and kept dry in the manner set forth by McAdam so long ago.

Over the years since his time there has been developed a wide variety of pavements, some patented which brought royalties to the promoter, but with the majority of types in the public domain. Brief mention of a few may be of interest. Stone block is one of the oldest types, varying all the way from selected gravel cobbles set in sand, to carefully cut granite bonded with some kind of mortar, composed of sand and either hydraulic or bituminous cement. Such pavements are to be found even today on heavy traffic city streets, and usually have proved very durable. In the latter part of the nineteenth century, brick pavements began to be widely used, and many miles of excellent construction with this type were placed, particularly in and adjacent to cities. As with stone block, many of these pavements are in use today, either in their original condition or as foundations under bituminous resurfacing. Wood block was another popular type

[illegible] wearing course, over compacted gravel.
Courtesy Alberta Government

[illegible] asphaltic concrete over flexible base.
Courtesy "California Highways and Public Works"

of paving, laid first to a considerable extent in England in the early part of the nineteenth century, and then subsequently in the United States, during the time when lumber was cheaply available. Wood block received public approval because of its ability to absorb noise, which was quite an advantage in the days of iron tires and iron shod horses.

These block pavements (except wood) usually were placed either on a macadam base or a lean concrete base, approximately 6 inches in thickness. Some kind of a cushion course (usually sand) was placed between the base and the block, which provided for adjustment of irregularities in the base. All of these pavements, when properly constructed, were capable of taking heavy traffic. They gradually have passed out of use, however, because with the increased cost of the manual labor required in present day construction, they simply could not compete with other types that can be placed largely by mechanical means.

USE OF ASPHALT IN PAVING

Asphalt paving first was used in France, early in the nineteenth century. Soon thereafter it was adopted for street paving in London, and was used in the United States for sidewalks as early as 1840. In this early use the material consisted of rock asphalt imported mostly from France. The first asphalt pavement composed of a mixture of asphalt cement and sand was laid in Washington, D. C. in 1876, the asphalt cement being imported from Trinidad. The use of asphalt advanced gradually thereafter until as early as 1902, approximately 20,000 tons of asphalt was being refined annually from petroleum. The portland cement pavement type, now popularly known as "concrete" was first called a concrete macadam. It was composed of a mixture of broken stone, sand and hydraulic cement, and the proportions were somewhat similar to those employed today. Often the pavement was placed in two layers, the second being rolled by hand to the desired cross-section.

Practically all of the pavements laid during this early period of construction were in cities because, until the development of the automobile, improved country roads consisted almost entirely of gravel or macadam, while the great majority had no pavement at all.

Regarding the subsequent developments, it is interesting to recall that, within the lifetime of a large number of the highway engineers at present in charge of state work, the entire building of the paved rural system has taken place. In 1915, for example, one of the chief topics of discussion at an annual meeting of highway engineers, was with regard to the merits of different kinds of drags for smoothing earth roads. Even in the twenties, one of the important committees of the Highway Research Board devoted a great deal of attention to improving the metal grader blades being used for maintenance of gravel roads throughout the nation, because replacements constituted such a substantial portion of maintenance costs. So rapidly have we progressed in the development of modern pavements that, even though at times it seems they are quite inadequate, it was but a few years ago that there were no pavements at all on the greater portion of the highway system which we now take so much for granted. It is with this history in mind, that the writer finds it difficult to become very much worried about any impending total failure of the highway system. He still recalls too vividly the experiences of driving *through* highways rather than over them, which even at the worst is a rare occurrence today. As a matter of fact, the modern car could have traversed very few states 35 years ago without becoming bogged down many times in making the journey.

Continued on the following page

SIX STAGES IN THE EVOLUTION OF

WASHINGTON-RICHMOND ROAD, NEAR DUMFRIES, VIRGINIA

IMPROVED WITH TRAFFIC BOUND GRAVEL

SURFACED WITH PORTLAND CEMENT CONCRETE

FUNDAMENTALS OF MODERN PAVEMENT DESIGN

Out of the experiences of these 35 years, and the improvements in technique brought about by keen competition between marketers of the different types of pavement, there gradually has emerged a rather definite pattern of the pavement design required to meet modern needs. Thus, every pavement, regardless of kind, should be a composite structure made up of three elements. See Fig. I. One is the ground itself, (A); second a base course of some kind, (B); and third the wearing surface (C). At times the natural ground is so strong that when processed properly it will in itself serve as a base, but even with the strongest soils, such as the granular types, it often is desirable to have a transition layer of some kind to better control the finished profile and cross-section. Frequently this may be done to advantage by stabilizing the upper portion of the soil layer with a bituminous binder.

These three elements might be termed the ABC's of pavement design. "B" will vary in thickness and quality according to the quality of "A", while "C" will be regulated by the requirements for waterproofing and providing resistance to traffic abrasion. Some of the factors that make for changes in the respective elements are climate, availability of aggregates of suitable quality, and the kind of traffic that will use the pavement. It is apparent that pavements usually must be stronger in wet, cold, climates than in warm, dry, ones, while the reasons for the other two factors also are self-evident. Qualified engineers are acquainted fully with the necessary modifications in this regard, and they are mentioned only to point out that the basic design of a modern highway is not complicated. To secure maximum strength, however, at lowest costs, there is a correct procedure, and for this the items required merit a brief review.

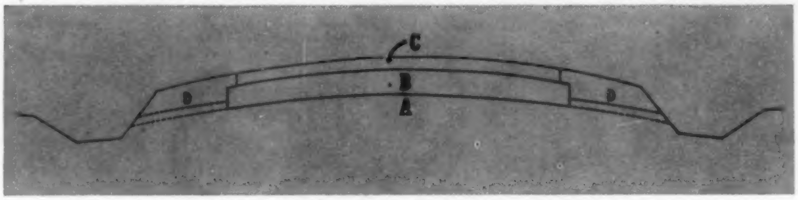


Fig. 1: A, The ground itself; B, a base course of some kind; C, the wearing surface; D, adequate drainage.

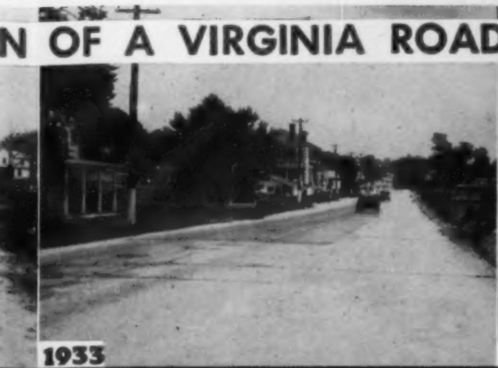
The natural ground is stronger when dry or nearly dry, than when saturated with water, so the first step is to insure that the ground remains relatively dry at all times. Referring again to McAdam, it is to be noted that great emphasis was placed upon proper drainage. Over and over again he stated that if the surface of the road be made waterproof, the sub-soil will be kept dry. Likewise, if the roadbed is properly drained by ditches, the sub-soil will be kept dry. That little word — *if*. Unfortunately it may be observed all too often *that roads are not drained* and *the subgrade is not kept dry*. The easiest and cheapest thing that could be done to make better roads, is not done, and on every hand ditches are often unnecessarily full of water or there are no ditches at all. One of the most pertinent observations ever made on the subject was by Professor Ben Petty of Purdue University, following a trip over a highway system. After his inspection he asked the maintenance engineer why the ditches didn't drain better. The answer was that they were temporarily stopped by landslides. "Maybe so," was Petty's laconic answer, "but those eight inch long fish the boys are catching didn't grow there yesterday." In certain soils this failure to provide proper drainage may be equal in terms of required thickness to as much as a foot or more of base material.

In general, the easiest way to obtain drainage is by making the roadbed in the form of an embankment. In flat country this embankment is obtained by cutting wide ditches and placing the excavated material between, thus leaving the profile of the roadbed several feet above the adjacent ground level. Even in rolling and mountainous country, where cuts are necessary, it is desirable to excavate a foot or more below the finished earth grade and to backfill with selected soil. Such simple procedures will insure drainage from the beginning, while routine maintenance thereafter should be enough to preserve it. It is fundamental for all roadbuilding, yet more millions have been wasted, and are now being wasted, through failure to provide drainage than from any other cause. Over and over again one will see an existing road which shows failures during the wet season, where the present surface could be made completely adequate simply by lowering the ditch line and thus lowering the ground water level under the roadbed. Even a plain earth road properly drained will require only a fraction of the maintenance smoothing that is otherwise needed.

ECONOMIC CONSTRUCTION CONTROL

The second fundamental in pavement design is adequate yet economic construction control, which includes every step in procedure literally from the ground up. The ground is known in engineering terms as "the subgrade" (See A, Fig. 1), and on this subgrade the pavement structure proper usually is placed in one or more layers, depending upon the conditions to be met. Now it is obvious that if the natural ground is unaffected by changes in temperature or moisture, it will retain its supporting power

N OF A VIRGINIA ROAD


1933
RESURFACING WITH ASPHALT


1937
ASPHALTIC CONCRETE SURFACE


1947
ASPHALTIC CONCRETE, ONE WAY TRAFFIC

unchanged throughout the year. For example everyone knows that sandy soils are firm when moist, while many clay soils change to soft, sticky mud. Consequently the supporting power of these stable soils is high, even with a relatively thin pavement. It is further apparent that when a new roadbed is being made and the profile is being adjusted by moving earth from one place to another, proper care in selection and placement of the last soil layers often may provide a subgrade that is little affected by these changes in temperature and moisture.

This care in selecting the best soils for the upper part of the newly-graded roadbed is one of the very real advances in modern engineering and is in marked contrast to the hit-or-miss grading operations of not so many years ago. The technique of placement of selected soils is called "soil mechanics" and by its use the engineer is able, with soil materials either on or immediately adjacent to the road, to improve supporting power very substantially and at costs much lower than formerly was the case. *The importance of this relatively recent development of "soil mechanics" cannot be overemphasized.* A very large part of the strength required for modern traffic can be obtained by building strong subgrades rather than by relying entirely on the surface construction, which of necessity must be composed of more expensive materials. The procedure should be required regardless of the kind of final pavement subsequently to be placed, because carefully prepared subgrades, plus drainage, constitute the only real permanent part of the entire road structure. In cases where soil alone may be inadequate it is often practicable to add chemicals or bituminous binders which may greatly improve the condition of support. Much research is now underway to develop such bearing power.

The next step in building a pavement is the base (B). If the natural soils are high in support, (and by careful selection or treatment they always can be greatly improved), this layer may at times be eliminated. A base, however, provides whatever additional foundation support is required at minimum cost, because usually it too is composed of less expensive construction than the wearing course (C). Sometimes it is composed of two or more layers, the lower portion being often called a *sub-base,* which may be of materials from nearby sources, such as sand, sandy loams, quarry wastes, gravels, shales, or a variety of materials of local character, with the upper portion only being of more carefully processed aggregates such as crushed stone, gravel, or slag. In any case all the materials should be uniform in quality and thoroughly compacted. A processed subgrade or base course, or combination of the two, is necessary for all types of pavements, and to omit them in any pavement design necessitates building a wearing course thicker and much more expensive than otherwise would be the case.

PLACING WEARING COURSE

Having provided the properly drained and compacted foundation, there remains only the placement of a wearing course which will provide waterproofing and resistance to abrasion under traffic. It is here that really great economies can be effected. In times past there has been too much reliance on building heavy surfaces in the hope that they would overcome deficiences in the subgrade. The evidence on every side would indicate that this is mistaken policy. In contrast we find that where strong subgrades and foundations have been built, the surface courses seldom need to be over four inches thick to carry the heaviest traffic. As a matter of fact, on airfield runways where wheel loads are far in excess of those of the heaviest trucks, even thinner surfaces have been satisfactory.

Modern surfaces fall into two broad classifications, flexible and rigid. Flexible surfaces may be as little as ½" in thickness for very light traffic, or as much as 8" thick, with an average of from 3" to 5". Rigid surfaces are seldom built less than 6" thick and often as much as 10" for highway use. Flexible surfaces are bonded with a bituminous cement, while rigid surfaces employ hydraulic cement.

The flexible surface plus the base, although it does not behave as a beam, is capable by reason of its density ***and continuous contact with the underlying earth subgrade*** of transmitting traffic loads without distortion. Flexible pavements are little affected by changes in temperature, consequently may be placed without joints; making it much easier to maintain a waterproof surface. They also are unaffected by salts and chemicals used for ice control.

A rigid surface is a system of beams which requires jointing at intervals in order to provide for expansion and contraction under temperature changes. Rigid surfaces do not make as full use of foundation values as flexible pavements because of a tendency to become separated from the foundation and to span the resettled areas of the underlying material. They are, however, greatly improved by placement of a base course of granular material which minimizes this tendency for separation.

Either type of pavement can be designed to take any traffic loading and the selection of the particular type accordingly comes down to the question of relative economy. Just as in the case of the block type pavements which became outmoded because of the manual labor required in their construction, so changing techniques are now affecting the respective costs for construction of flexible and rigid pavements. While the great improvements in equipment for placing flexible pavements has had a profound influence in reducing their cost as compared with former hand labor methods, a principal advantage lies in ability to control thickness of surface in ***exact relation to traffic needs*** and to utilize local materials in construction. With present costs, potential savings in favor of flexible design are large, sometimes as much as sixty per cent.

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HIGHWAY PAVEMENT DESIGN

Idaho — State Route 15, near Cascade 2½" Hot-Mix asphalt wearing surface over 6" gravel. *Photo Banning*

New York — U. S. 9W, South of Round Lake in Saratoga County, asphaltic concrete on flexible base. *Courtesy New York State Department of*

ASPHALT ROADS ARE GROWING WIDER

[illegible]
Middle: Russell Cave Pike in Fayette County, Kentucky.
Bottom: On State Route 33, north of Griggs Dam, Ohio.
Photos Hinkle

PAVEMENT WIDTHS

The width of a pavement greatly affects its ability to carry the traffic and a principal deficiency in the highway system today is lack of balance between the older narrow pavements and the modern vehicle. The Roman roads were about 14 feet in width. This accommodated foot troops, chariots, and wagons. The surfaces built by Telford and McAdam usually were 15 feet wide and were designed to carry horse-drawn wagons and carriages. The early state roads in Massachusetts for example, were paved 15 feet wide for the same kind of traffic. With early auto traffic and higher speeds, another foot was added and many of the pavements built in the twenties were still only 16 feet wide.

By the thirties 18 foot widths were becoming usual but, to this day, nearly half of the state highway pavements are only 20 feet or less, while the increased size and speed of the present-day motorized traffic requires 24 feet of width to allow equal mobility as compared with the slower traffic of only a few decades ago. Widening all main traffic arteries to this latter width will permit efficient movement of 400 vehicles or more per hour and at the same time reduce maintenance costs. Widespread improvement of this kind will do more to *increase safety* on the highways than any other single item.

There is one other item in width design that deserves attention. When traffic much exceeds 400 vehicles per hour it usually becomes desirable to construct a dual highway. For some obscure reason it has been felt necessary for such an improvement to construct a heavy duty pavement thereon, whereas the need often is merely to provide room for a large number of light vehicles. This is true particularly of parkways, or roads leading to recreational areas. Often the heavier traffic is seasonal during the very period when subgrade support is highest. Such routes can be paved at costs usually of less than half of those now being built, by taking full use of the flexible design procedures.

CONCLUSION

In summary then, it can be said that this great highway system of ours is as dependent on proper planning and the consistent application of economical construction methods as it is on increased revenues.

Without doubt, whenever a project is to be built, no matter how large or how small, each engineer having any part in the design must be guided by a control plan which will properly fit that project into the integrated highway scheme. Each phase of design must be consistent with economy of construction, including the maximum practical use of local materials. Soils and base material should be "up-graded," and surface types should be selected which will take full advantage of every supporting factor available.

The never-ending cycle of change and improvement is today dictating a *re-appraisal* of construction methods in many localities, and the sooner these modern practices and economies are placed in operation, the sooner the traveling public will be realizing a one hundred per cent return for each highway dollar invested.

END

LIFE CHARACTERISTICS OF FLEXIBLE PAVEMENTS

How long should a pavement last? The answer is something like Abraham Lincoln's famous reply to the question, "how long should a man's legs be," when he stated with perfect logic, "long enough to reach the ground." So, a pavement should be adequate for the traffic it is to carry today. It is of course reasonable to anticipate some period of future growth, but this should be in the nature of provision for additions when the time comes rather than making an earlier over-design which will not be utilized fully for many years. The road, the traffic, and the revenue it provides, should be rationally coordinated. For this, the engineer must carefully calculate the life expectancy of each component part of our entire road system.

It is evident that in order to properly evaluate any highway surface, it is necessary to know not only *what has happened* but what is happening now. Many miles that would ordinarily have been reconstructed, have been given a *resurfacing treatment* to keep them in operation temporarily, as a result of the wartime conditions. This temporary condition, and one formerly considered a maintenance item, certainly has become rather permanent, not only from necessity but through the excellence of the results obtained. There is no doubt that thousands of miles of road, which appeared to be at the end of their useful life, have thus become able to take current traffic in a satisfactory manner and *that they will continue to do so indefinitely.*

A ROAD HISTORY STUDY

This satisfactory behavior, over a large mileage, led to a study by the Asphalt Institute of a number of individual road project histories, *to find out exactly how much had been expended over a long period of years,* and to appraise the adequacy of each road in respect to traffic needs from the time of first improvement to the present day. For the study a state was selected in the industrial northeast, where traffic is heavy, subgrade conditions not too good, and where severe winter hazards prevail. Seven of these road projects are reported, to show the range of costs, traffic etc., in the "Pertinent Data" Table on page 13 herein. Three of these same projects, covering heavy, medium, and light traffic, separately shown in Tables A, B, and C on that page, are discussed in detail on page 12 to point out how each annual expenditure contributed to the improved condition now prevailing.

Most of these roads started with an initial improvement of traffic-bound macadam. The existing earth road was bladed to a smooth cross-section, following which an inch or so of crushed stone or gravel was spread to form a sort of earth-bound macadam. Each year thereafter, for several years, and when the roadbed was soft, additional stone or gravel would be added until a stabilized condition was achieved. Maintenance was accomplished by blading and dragging the surface during the remainder of the year. The process was temporarily hard on tires and windshields, but it provided for a rather rapid improvement and the process developed a large mileage which sustained the traffic.

At first, such a roadway was usually full of curves, and in the years which followed, much of the money charged to maintenance actually was expended in improving the alignment. The net effect in this regard has been to make many of these old roads as easy riding as new locations. As a matter of fact some are better, because the curves were spiralled in the maintenance process rather than being conventional circular curves which so often make for abrupt transitions. This realignment involved additional paving and even provided three lane movement on the sharper curves. In addition to widening, curves often were super-elevated, together with reduction of crown, as many of the early surfaces were as steep as $\frac{3}{4}''$ per foot, while modern requirements do not exceed $\frac{1}{4}''$ fall per foot from the center to the pavement edge.

A THIRTY-SEVEN YEAR TRANSITION

THEN

NOW

[illegible] Pohick Church, Virginia, as it looked in 1914.

The same "view" today after many improvement stages, paved with asphaltic concrete.

[illegible]

The pavements covered in this study are today better than at any time in their previous history. In addition to improved alignment, the weak areas in the original base courses have been sufficiently thickened by patching so that uniform load support has been secured. They have been widened sufficiently in most cases to meet the current needs but can be widened further as may be necessary. Like all other highways they took a severe beating during the period 1941-46,

Continued on the following page

with only nominal maintenance, but recent betterments not only have restored them to 1941 condition, but have improved them so as to be adequate for current traffic.

In analyzing these roads, and they are typical of many miles throughout the country, one may ask what was the salvage value of the old pavement? In view of the fact that all of these roads, like many thousands of others, are now far superior to their original condition, it must be evident that at any given period, ***skilful stage construction development makes for one hundred per cent salvage of existing values.***

In making other studies throughout the country, it is to be noted that, with rather few exceptions, maintenance costs are difficult to obtain for the years subsequent to 1945. Many states do not keep detailed costs at all, or at least do not combine reports from the field offices so that an over-all picture can be obtained readily. The following data, however, is complete and representative of stage construction costs throughout the country.

TABLE A — ROAD #1

Present length—5.3 miles.

Project originally was 7.7 miles in length, with two sections subsequently included within expanded city limits. Located on the Interstate System, one section carries heavier traffic because of intersection with another state road. Present traffic averages from 8,000 to 16,000 vehicles per day, of which 1,600 are commercial, including 700 trailer-type trucks. Initial improvement prior to 1914 was traffic-bound macadam, approximately 16 feet wide. In 1915, a 3 inch penetration macadam surface was placed. In 1926 the pavement was widened to 18 feet with waterbound macadam. In 1928 it was widened to 24 feet with waterbound macadam, the entire width then surfaced with 3 inches of penetration macadam. In 1940 the road became part of a dual highway so that all subsequent traffic was in one direction. In 1949 a $2\frac{1}{2}''$ hot-mix asphalt surface was placed. The total thickness is now from 12 to 15 inches. The subgrade is a heavy loam, annual rainfall about 45 inches. Present condition of the pavement excellent and adequate for the very heaviest traffic. As shown in Table A, maintenance costs varied from year to year as deficiencies in the original foundation were corrected by the comparatively expensive process of patching the settled areas, yet the over-all cost still is low. Area maintained and costs were as shown for the various periods.

See table A, Road #1 on opposite page

TABLE B — ROAD #2

Present length—8.5 miles.

It is located on the State Primary System, near a small city, on one of the main cross-country highways. Traffic averages 2,400 vehicles daily, of which 540 are commercial including 220 of the trailer type. In contrast with Highway #1, this roadbed was substantially a newly constructed grade of the kind built in the early twenties, on which a pavement 18 feet wide was placed, consisting of 8" waterbound macadam base and a 2" plant-mix asphalt surface. The subgrade, however, was not stabilized and considerable settlement occurred in the years immediately following. This necessitated much patching to maintain a smooth riding surface. In 1932-33, the pavement was widened from 18 to 20 feet and resurfaced with a 2" plant-mix asphalt. In 1944 a resurfacing of $2\frac{1}{2}''$ plant-mix was placed. Over the period of twenty-two years, a surface had been achieved that is now far superior to the one first built. The weak spots in the subgrade have been stabilized and the present thickness of pavement is approximately 14 inches. At the age of twenty-five years (1947) maintenance charges were declining (See Table B), and for the current decade will not exceed 1c per square yard per year. This project has been unchanged in length since its first construction.

See table B, Road #2 on opposite page

TABLE C — ROAD #7

Present length—20.8 miles.

This is a state road of low medium traffic. Present average is 400 vehicles daily, of which 110 are commercial including 80 heavy trucks. This road represents as complete a "Topsy-growth" as could be imagined. The old earth road representative of many thousand miles on the secondary system was scarcely more than a trail in 1916 and practically impassable in the wet season. It never had a construction contract as such; first one mile, then another was improved, then by sections of several miles it received various bituminous treatments until today, over thirty years later, it carries fairly heavy traffic and permits safe legal speeds throughout. It is of variable width, with 18 feet as a minimum. The first surface was marl, a very soft limestone which can be bladed when first placed, and later hardens to a firm condition. Some gravel was added in the road-mix operations. The present thickness is about 8 inches. It is a typical example of how intelligent maintenance expenditures are in reality producing a new pavement.

In such developments, the state was faced with the necessity of quickly improving a large mileage, rather than placing all of the funds in one super-mile while others remained in the mud. The policy of course was fully justified, not only from the standpoint of political expediency but because where twenty miles were improved in one year instead of one, traffic was immediately taken out of the mud for that distance and consequently contributed in greater degree to revenues for succeeding years. It would be hard to say that at any time this pavement had an expected life of a particular duration but today, after thirty-five years, an excellent highway has been obtained and at a very low cost. See Table C.

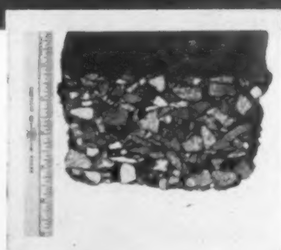
See table C, Road #7 on opposite page

Forty-One Year-Old Denver Pavement

Pictured to the right is West Colfax Avenue, in Denver, Colorado, with an inset showing a cut cross-section of its pavement, removed in June 1951.

This bituminous pavement was constructed forty-one years ago, using petroleum asphalt and carries a daily average traffic of 16,000 vehicles. No major maintenance project of any nature has ever been constructed and it is estimated that the total maintenance costs on this street have averaged but \$0.002 per square yard per year.

The pavement is $4\frac{1}{2}$ inches and is constructed on the natural soil, a granular material. It consists of a 3 inch asphalt penetration binder course and a $1\frac{1}{2}$ inch sheet asphalt top. A 50-60 penetration asphalt was used, and extractions made in June 1951, show the asphalt to have a penetration of 45 plus.



West Colfax Avenue, U. S. Route 40 — one of the more heavily travelled streets in Denver with inset showing typical cut-section sample of its asphalt pavement.

Photo Banning

Pertinent Data on Flexible Pavement History for 7 Projects, Ages 26-34 Years*

ROAD NO.	SOIL TYPE	ORIGINAL SURFACE	PRESENT LENGTH	WIDTH ORIGINAL	WIDTH PRESENT	PRESENT AREA Sq. Yds.	YEARS COVERED	TOTAL CONSTRUCTION (a) COSTS PER SQ. YD.	ANNUAL MAINTENANCE (b) COSTS PER SQ. YD. (AV.)	TRAFFIC COUNT (c) 1948	PRESENT CONDITION
1	Clay loam	Traffic-bound stone	5.3 mi.	16′	24′	75,000	1915-1949	$2.62	$0.039	8,000 West Sec. 16,000 East Sec. (1,600 commercial)	Excellent
2	Clay loam	New earth grade	8.5 mi.	18′	20′	100,000	1922-1947	3.32	0.024	2,400 (540 commercial)	Excellent
3	Clay soil	Traffic-bound stone	14.7 mi.	16′	20′	173,000	1915-1948	2.86	0.021	1,000-2,100 (200-300 commercial)	Excellent
4	Clay loam	Traffic-bound stone	1.9 mi.	16′	22′	24,700	1915-1948	4.41	0.023	1,750 (260 commercial)	Excellent
5	Clay soil	½ length fair macadam	6.8 mi.	17′	20′	80,300	1921-1948	1.65	0.022	1,500 (240 commercial)	Excellent
6	Clay loam	Traffic-bound stone	2.6 mi.	14′	20′	30,200	1914-1949	2.79	0.023	1,200 (210 commercial)	Excellent
7	Clay loam	Only a trail	20.8 mi.	16′	18′	222,500	1916-1949	1.17	0.026	400 (110 commercial)	Good Needs 80# Treatment

*Throughout the history of these pavements, only flexible type materials and construction were used.

Notes: (a) Total Construction Cost includes all expenditures since first year noted.
(b) Annual Maintenance Cost is total expenditures per square yard divided by years since first year noted.
(c) Commercial traffic approximately 10-20%, with heavy vehicles nearly half the total.

CONCLUSION

These road cost tables record examples typical of the construction of thousands of miles of highways in the United States, which make it possible to operate the nearly fifty million vehicles of today. With this form of *stage construction,* where funds are expended in the most economical manner and *only in amounts necessary to accommodate the vehicular requirements of each demand period,* every highway dollar has been given its maximum use.

How can highway funds be more effectively used than to spend, as shown in Table "A" for Road #1, but 35c per square yard for construction in the first eleven years of service, which was adequate for the traffic of that time; and with a *total* expenditure of less than four dollars a square yard (both construction and maintenance), covering *thirty-four years of service,* to produce for today's heavy traffic a fine, modern highway carrying an average of 16,000 vehicles per day? Is this not the best highway life, when adequate service is maintained over a highway for thirty-four years with *all* costs of that highway less than the new construction costs alone of many competing types?

How shall we figure the *service cost* of a pavement? Is it not the ratio of total cost to the years of satisfactory and adequate service? As the years of service increase, the cost per year diminishes. Certainly it can be said then, on the basis of service history, that the life of a flexible pavement, as in Lincoln's definition, is long without limits, and that every dollar placed in it can and will be well utilized in any future changes dictated by traffic requirements.

END

TABLE A — ROAD #1

YEARS COVERED	SQUARE YARDS	CONSTRUCTION COSTS PER SQUARE YARD	MAINTENANCE COSTS PER SQUARE YARD PER YEAR (AV.)
1915-1926	72,000	$0.35	$0.054
1926-1928	81,000	0.10	0.039
1928-1939	108,000	0.74	0.035
1939-1941	100,000	0.00	0.034
1941-1947	95,000	0.00	0.024
1947-1949	75,000	1.18	0.024
TOTAL COST TO 1949—34 YEARS	75,000	$2.62	$1.36
AVERAGE COST PER YEAR	75,000	$0.077	$0.039

TABLE B — ROAD #2

YEAR COVERED	SQUARE YARDS	CONSTRUCTION COSTS PER SQUARE YARD	MAINTENANCE COSTS PER SQUARE YARD PER YEAR (AV.)
1922-1932	90,000	$2.30	$0.037
1932-1943	100,000	0.69	0.019
1943-1947	100,000	0.57	0.003
TOTAL COST TO 1947—25 YEARS	100,000	$3.32	$0.61
AVERAGE COST PER YEAR	—	$0.133	$0.024

TABLE C — ROAD #7

YEARS COVERED	SQUARE YARDS	CONSTRUCTION COSTS PER SQUARE YARD	MAINTENANCE COSTS PER SQUARE YARD PER YEAR (AV.)
1916-1926	222,500	$0.49	$0.020
1926-1936	222,500	0.37	0.032
1936-1946	222,500	0.22	0.023
1946-1949	222,500	0.09	0.036
TOTAL COST TO 1949—33 YEARS	222,500	$1.17	$0.67
AVERAGE COST PER YEAR	222,500	$0.035	$0.026

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For this managing-engineering post Mr. Wellborn's training, following his course at the University of Arkansas Engineering School, included first, employment by the Arkansas Highway Department in the Department of Materials and Tests from 1933 to 1940. There his last position was as Soils Engineer, pioneering in the work in asphalt soil stabilization.

Then followed two years of employment with an asphalt pavement construction firm as Chief Engineer and Assistant Manager, in charge of engineering projects in Ohio, Louisiana, Arkansas, and Texas.

In 1942, Mr. Wellborn entered the U. S. Navy, serving in the South Pacific, Alaska, and Washington State, with the rank of Lieutenant Commander. After an interval of one year in general contracting, in 1947 he was employed by the Navy as Engineer in Charge of Design and Construction of airfields in Cuba, resigning in August 1949 to accept his present position with The Asphalt Institute.

Mr. Wellborn is a Registered Professional Engineer and his membership affiliations in technical and other associations include the American Society of Civil Engineers, the American Chemical Society, and the American Road Builders Association.

John M. Griffith, with headquarters at the New York Office, is the newly-appointed Engineer of Research. He succeeds to the post held by Prevost Hubbard, retired, as head of the Institute's laboratory and field research.

Mr. Griffith received the degree of Bachelor of Science, Civil Engineering, from the University of Michigan. His background of training and experience includes first, work with the U. S. Coast and Geodetic Survey in Florida, Alabama, Mississippi and North Carolina, followed by employment with the Mississippi State Highway Department on general highway planning. In Michigan in 1938 and 1939 he served as Office Engineer in the City Engineer's Office at Ann Arbor, and then for two years with Professor W. S. Housel in consulting work on soil mechanics and foundations at the University of Michigan.

For the past eight years Mr. Griffith has been with the Flexible Pavement Branch of the Waterways Experiment Station at Vicksburg. This is a research branch of the U. S. Corps of Engineers operating directly under the Chief of Engineers, Department of the Army. In November 1944 he was promoted to Chief of General Investigation Section; and in October 1947 re-assigned as Chief of Bituminous and Chemical Section, handling all laboratory research and a number of special projects of the Branch.

Mr. Griffith is an Associate Member, American Society Civil Engineers; Member, American Society for Testing Materials and of the Association of Asphalt Paving Technologists; Associate in Highway Research Board; and Registered Professional Engineer (Civil) in Michigan.

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